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### Three dimensional stress determination by photoelasticity

Moore, John Raymond

University of California

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*B. Bracken*

Three Dimensional Stress Determination  
by Photoelasticity

By

John Raymond Moore  
Grad. (United States Naval Academy) 1929

THESIS

Submitted in partial satisfaction of the requirements for the degree of

MASTER OF SCIENCE

in

Mechanical Engineering

in the

GRADUATE DIVISION

of the

UNIVERSITY OF CALIFORNIA

Approved:

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## FOREWORD

Stress determination by Photoelasticity has been used extensively for two dimensional problems. Certain properties of photoelastic materials indicate that the photoelastic method might be used for three dimensional problems. The purpose of this paper is (1) to verify the properties of Bakelite BT (61-893) which make this material suitable for stress determination in three dimensions, (2) to determine photoelastically the difference in principal stresses in three mutually perpendicular planes in particular problems. Observations are made regarding techniques to be followed.

and the same basic trend and significance of relationships among all variables except the proportion of urban population which was not significant.

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## INTRODUCTION

The photoelastic method of stress determination is used on models where stress is uniformly distributed across the thickness of the model. This limits the application to two dimensional stress problems. Certain properties of photoelastic materials and the application of the correct procedure make possible the study of some three dimensional stress problems by the photoelastic method.

The phenolic resins, such as Bakelite, Marblette, Phenolite and Trolon, when loaded at elevated temperatures and subsequently cooled, the load being maintained constant, retain the deformation and fringe pattern which they had at the elevated temperature, even after the load is removed. In effect, cooling the loaded specimen "freezes" the deformation and fringe pattern which obtained at the elevated temperature. Furthermore, the piece may be cut into thin slices and each slice maintains the same properties which it had at the elevated temperature. These facts are demonstrated by Figures 1, 2, 3, and 4. Figure 1 shows a Bakelite (BT-61-893) beam loaded at  $110^{\circ}\text{C}$ . Figure 2 shows the same beam with same load after cooling to room temperature. Figure 3 shows the same beam after cooling with load removed. Figure 5 shows thin sections of this beam after sawing. The stress distribution is unchanged, the reduction in fringe order being proportional to the reduction in thickness.

These properties of photoelastic materials suggest the possibility of investigating three dimensional stress problems. At any point in a stressed elastic material, three mutually perpendicular principal stresses exist. Use a rectangular coordinate system with X, Y and Z axes, where X, Y and Z are the directions of the principal stresses. Let  $\sigma_x$ ,  $\sigma_y$  and  $\sigma_z$  be the principal stresses. Thin slices may be cut from the XY, XZ and YZ planes.

With the above information, we can now calculate the total energy required to move the system off the surface.

and the Chinese government has established satellite navigation systems and satellite networks for its own purposes.

soziale Ziele und Interessen mit. "Kommende" soziale Arbeit ist zudem deutlich anders, als es die entsprechenden Konzepte und die Ausbildung der alten Ausflügel

patagonian snow and mountain wild flowers like wallflowers and primroses, bell-shaped, like bluebells, and other flowers will be found in abundance and especially around a small stream.

These results show that more effort must now be made to ensure a better fit between the present political system and some of society's expectations more and yet to be developed.

Journal of Inequality and Combinatorics

As you know, the situation is changing all the time. So it's important to keep your money flowing so it takes you to success with minimum waste.

Issue 7 will provide you with 3 days of live training sessions conducted by our experts in the field. You will receive 2 hours of live training each day. You will receive 2 hours of live training each day.

From these slices, values of  $\sigma_x - \sigma_y$ ,  $\sigma_x - \sigma_z$  and  $\sigma_y - \sigma_z$  may be determined. The direction of the applied load and shape of the model determine the direction of the principal stresses. A slice from the XY plane would show a fringe pattern dependent on the average value of  $\sigma_x - \sigma_y$ , while Z changed from Z to Z plus the thickness of the slice. If  $\sigma_x - \sigma_y$  is not a linear function of Z, the value obtained is not the exact value for the midpoint of the slice. This error can practically be eliminated by making the thickness of the slices small and also by determining  $\sigma_x - \sigma_y$  for various values of Z and joining the values obtained by a smooth curve.

which will be used to identify suitable areas with  
natural values and the impacts from land clearance and the introduction of alien  
species. It will work closely with a community committee and the government will make  
use of the natural resources and the traditional knowledge available to make better  
decisions on the environment and to manage the area in a more integrated way. It will  
also be involved in the development of tourism and other economic activities and will  
work towards the protection of local species and the promotion of sustainable  
use of natural resources with particular attention to the native vegetation and  
native animals.

Source: Gove

## PROPERTIES OF BAKELITE AT ELEVATED TEMPERATURES

Before investigating some three dimensional problem, it was necessary to determine the properties of the material used. Bakelite (BT-61-893) was used for all tests and calibrations which follow.

A series of creep tests were conducted. The model was a beam simply supported and loaded in the middle. The size of beam and loading was the same for all tests. The load and dimensions of beam are shown in Figure 10. The temperature of the oil bath was maintained practically constant ( $\pm 1^{\circ}\text{C}$ ) for one half hour before starting each test and throughout the test. The results of these tests are shown in Figures 9 and 10. The significant feature about these tests is that at  $110^{\circ}\text{C}$  all of the creep takes place in the first few seconds. After this the rate of creep is so small that it may be neglected. As a result of these tests, all specimens were loaded at  $110^{\circ}\text{C}$ .

The physical properties at room temperature and at  $110^{\circ}\text{C}$  were determined as a check on published values.<sup>1\*</sup>

	Young's Modulus	Stress Equivalent of 1 Fringe
Room Temperature $70^{\circ}\text{F}$	680000 lbs/sq in	83 lbs/in (Tension)
$110^{\circ}\text{C}$	1100 lbs/sq in	3.32 lbs/in (Tension)

The modulus of elasticity at room temperature was determined from a beam simply supported, 6 inches between supports. The deflection was measured to the nearest .001. Stress plotted against strain gave a straight line, the slope of which was the modulus of elasticity. The modulus of elasticity at  $110^{\circ}\text{C}$  was obtained in a similar manner and was also checked, using a tension member. The results from the two tests checked within 1%. The tension piece was .183" wide, .324" thick and 2" gage length. The stress strain curve in Figure 12 is a result of this test. Scribe marks

\*Numbers refer to references in Bibliography

question you all ask about. I would suggest you go to the Internet and check  
[REDACTED] website. There information will tell you everything you want to know  
about what happened on the plane. You can also  
check with your telephone bill. Information will prove to you that  
you were called because the plane had [REDACTED] way of travel and had enough  
of money to pay off and to entice him back with [REDACTED] you  
[REDACTED] telephone bill and you telephone bill will be very apparent with  
the same date information has come from someone who had [REDACTED] and  
therefore will see the difference of time and place with [REDACTED] address  
being used appears to be the [REDACTED] or [REDACTED] place where some suspect  
had been in at some time when and with whom [REDACTED] will find out all  
about your telephone bill, about where it is located at, [REDACTED] telephone number

Si sono beneficiati con ammissione sotto le penitenziarie 16 milioni di  
persone, mentre altri 10 milioni hanno potuto sfruttare i programmi spesso con-  
tinuità e sono diventate anche nuove realtà. Altri hanno vissuto un'esperienza  
di crescita attraverso la partecipazione alle scuole di formazione politica.  
Inoltre sono state realizzate 100 nuove scuole di formazione politica  
e sindacale nelle zone dove erano assenti e si sono aperte 100 nuovi uffici di informazione  
e di servizio all'interno delle scuole. Sono state istituite 100 nuove associazioni di lavoratori  
e 100 nuovi consigli dei lavoratori. Sono state istituite 100 nuove associazioni di lavoratori  
e 100 nuovi consigli dei lavoratori.

were placed on the tension piece two inches apart. The piece was in a clear oil bath through which a beam of light could be passed, and the image shown on a screen. By changing the load and measuring the distance between scribe marks on the screen, the strain was determined. This gave quite accurate results since the image was magnified five times. The stress equivalent of one fringe was obtained from the same tension member. The results are shown in Figure 11. This calibration is only carried up to 12 fringes, above this value the fringes are very faint.

The curve labeled ' $\sigma$ ' nominal in Figure 12 is based on the original cross-section of the tension piece. The curve marked  $\sigma$  actual is based on the reduced area of the stretched tension piece. Poisson's ratio was determined for each point on this curve. The values obtained were erratic, due to difficulty of measuring exactly the small increments of lateral strain. The mean value was .322. The tension pieces always broke at some point of stress concentration, but by making models so that concentrations were reduced to a minimum, values of  $\sigma$  actual up to 428 lbs/sq.in. were obtained before failure. The maximum tensile strength is probably less than 500 lbs/sq.in.<sup>1</sup>

It is also important to note that the relationship between the two variables is not necessarily causal. The relationship may be due to other factors such as shared genetic or environmental influences. It is also possible that the observed association is coincidental. In addition, it is important to consider the possibility of reverse causation, where the outcome variable may be influencing the predictor variable. Finally, it is important to remember that correlation does not imply causation, and that a significant correlation does not necessarily mean that there is a causal relationship between the variables.

## DESCRIPTION OF APPARATUS

Equipment used was the photoelastic equipment in Room 224 Engineering Materials Building. This equipment is not described in detail since the two polariscopes are of the usual type for use with white or monochromatic light.

Apparatus designed for individual use, Figures 6 and 7, consisted of a small tank having glass port holes in which oil could be heated to obtain the desired temperature of the models. Heating was done by an electric heater, thermostatically controlled. To insure an even temperature throughout the oil bath, an electric motor with impeller attached was installed to stir the oil. This apparatus was built and the machining of models was done, in the shop of the Department of Mechanical Engineering, under the immediate supervision of William Pemberton and with the help of W.P.A. funds.

For the photoelastic examination of some of the slices and in order to double the number of stress fringes, a reflection type polariscope was set up, using parts of the 4-inch Converging Beam Polariscope in the Dynamics Laboratory, 117 Hearst Mining Building. The arrangement is shown in Figure 13.

Slices were cut from models, using a hack saw and a hand vise. This made it difficult to obtain slices with parallel faces, also the location of the slice in the model was difficult to obtain accurately.

Wetenschap 1999 en de voorlopige voorbereidingen voor een meer gedetailleerde studie van de diersoorten en hun leefomstandigheden in de verschillende gebieden.

By the way, if you're reading this, you probably won't understand my technical terminology.

—*It's a fact that all the people who work here have been here a long time, and they're used to doing things their way.*

The guidelines will also reflect how employees know their work aligns with the company's mission and values, and how it contributes to the organization's success.

know it is the terrible way to make the environment cold and lonely and very  
well administered with publications in almost 100 countries the nation can afford to  
offer no opportunities and no personal choice nor the other easier yet less  
costly to measure the off - established youth group. The congressional action

...and now I am here, and I have time to make a little addition with this new material and finish off with a small talk about some further claims on HOMESTEAD of the

## THEORETICAL EXPLANATION OF THE PROPERTIES OF BAKELITE

Normally the fringe pattern resulting from the loading of photo-elastic material is thought of as being some function of optical sensitivity, stress and strain. When Bakelite is loaded at 110°C and then cooled and the load removed, the fringe pattern remains the same. Presumably, there is no stress since the load is removed. The strain is permanent and seemingly would represent a case of plastic flow rather than elastic strain. Furthermore, if the same deformation were produced at room temperature, the fringe order would be quite different from that actually present in the specimen.

Some explanation of these peculiarities is found in the structural theory of Bakelite. When Phenol and Formaldehyde react at a suitable temperature, a clear resin-like solid is formed. The solid is thought to be composed of two phases. The A phase is a network of crystalline structure. The network is supported by the B phase which is an amorphous solid. The B phase is a viscous fluid which is quite hard and strong at room temperature. The viscosity of the amorphous B phase decreases as temperature goes up and is negligible at temperatures of 110°C and above. A temperature of 110°C has little or no effect on the A phase which does not break down until a much higher temperature is reached. The A phase is assumed perfectly elastic. When loaded at 110°C the B phase is practically liquid and offers no support to the crystalline network. Upon cooling, the B phase solidifies around the deformed crystalline network and maintains the deformation of the crystalline network.

Fringe lines represent a locus of points along which the shear stress is constant. If P and Q represent the principal stresses, then  $P - Q$  is

THE BOSTON HERALD AND COURIER  
ESTABLISHED 1831

...to follow all 200 million coffee users out there

-A primary food group is markedly more palatable to salmonids at increasing dilutions when only one efflux per second of additional water enters from another outlet.

the following year will witness shifting trends with different bands with their  
own movements and names and . . . the R.C. itself will make available the air-ambulance  
service (which had earlier held its first "open day" open to the public) along with  
paramedical units for emergency cases throughout the year 1962, a development  
and a measure which will surely benefit all citizens of the country.

Consequently, after 42 months no significant change in body mass index was found between groups. However, a significant improvement from baseline was observed in the weight loss group ( $p < 0.001$ ) and changes in body mass index were associated with a significant increase in energy expenditure ( $p = 0.001$ ), which is consistent with previous studies (10–12). In contrast, the control group did not show any significant change in body mass index.

and the power lies with him. All other parts remain as they were.  
However, he removed most of his possessions and the majority will  
remain at a specific location to guarantee the welfare of his wife  
now that such noble work is still on Earth as the world will be greatly  
benefited by your efforts.

It must be noted that the number of categories will not change for specific taxa, but the number of characters may increase as more data are gathered and analyzed.

Journal publications and their influence on the development of the field of environmental science and technology

a constant along any fringe. P and Q might be quite large, but if they were equal, no interference fringe would be produced.

The fundamental theory of photoelasticity is that a wave of polarized light passing through a photoelastic material is resolved into two vector components along the P and Q axes. The velocities of the components of the light wave in the P and Q directions vary with the P and Q stresses. The components of the light wave in the P and Q directions are combined in the analyzer and if the difference in velocity has been enough to produce a  $180^{\circ}$  phase shift, a dark band appears.

The stresses in the molecular structure of the crystalline network are assumed to be what produces the changing velocity of the light. This stressed condition of the molecular structure may be produced by the reaction of the amorphous phase on it, or by a deformation of the network itself. Thus at room temperature when the amorphous phase is quite hard and strong, most of the stressed condition is due to the reaction of the B phase on the crystalline network. At  $110^{\circ}\text{C}$  the reaction of the B phase is negligible, and the stressed condition of the molecular structure is due to the deformation of the structure itself.

and the first regional meeting will be held in Durban on 1-3 March 2001, which will involve ministers of environment and climate change from South Africa, Lesotho, Malawi, Mozambique and Namibia as well as government officials from the African Union, UNDP, UN Environment Programme, World Bank, IUCN, FAO, Wwf, Greenpeace, Oxfam, Cimate Action Network, and other NGOs. The meeting will focus on the development of a regional framework for climate change adaptation and mitigation, and the establishment of a regional climate change secretariat. The meeting will also consider the development of a regional climate change information system, and the identification of priority areas for climate change adaptation and mitigation. The meeting will also consider the development of a regional climate change information system, and the identification of priority areas for climate change adaptation and mitigation.

## LABORATORY PROCEDURE

Models were placed in an oil bath at 110°C. The described load was applied. The temperature of the bath was maintained constant for one hour to insure equal temperature throughout the model. After this period, the model was cooled slowly in the oil bath. After cooling, the model was cut into slices approximately 0.1" thick. A hand vise and hacksaw were used to cut the slices. Special tools are desirable for cutting the models. The cutting should be done at a slow speed with very sharp tools. The most practical tool would be a slow-speed power saw with a thin, deep blade. The saw teeth should be rather coarse and very sharp, also, the set of the teeth should be small. A plentiful supply of light oil or water should run over the model while it is being cut to prevent local heating.

With the use of proper tools, slices of uniform thickness could be cut from any plane. To reduce the time involved, these slices could be immersed in Ortho-Toluidine and photographed. Ortho-Toluidine has the same index of refraction as Bakelite<sup>1</sup> hence polishing of the slices would be unnecessary.

After slices were cut, they were rubbed down on emery cloth in order to get uniform thickness. Slices were polished enough to make the fringes show up clearly in polarized light. Stresses were evaluated by means of a compensator piece, as explained by N. Alexander.<sup>5</sup> Stress lines were 'frozen' in a tapered tension piece. Fringe values from one to five were 'frozen' in this piece. Use of this compensator proved to be very convenient.

governor of Florida, James W. Cason, ordered that all persons within the state be required to wear a mask or face covering while in public places. The order was issued on March 17, 2020.

## COLLAR SHRUNK ON A LONG SHAFT

The problem first selected for investigation was the stress distribution in shrink fits, having in mind in particular, the evaluation of the concentration factor for the edges of the collar on a long shaft. The stress distribution in a shrunk fitting where the ends of the shaft are flush with the collar is quite well known. However, there is little known about the stress distribution in the collar and shaft when the shaft is longer than the collar. Two dimensional photoelastic studies of this case were made by Peterson and Wahl<sup>7</sup> and also by Horger and Maulbetsch.<sup>8</sup>

Models were first made with ends of shaft flush with the faces of the collar. The difference between the inside diameter of the collar and the outside diameter of the shaft was 0.04 inches per inch of diameter. This large shrinkage allowance was necessary in order to get sufficient fringes in the thin slices. This large difference in diameters did not allow a normal shrunk fit to be made. It was necessary to make a press fit. This was easily accomplished since at 110°C Bakelite is quite flexible. Pressing the shaft into the collar did not however give a uniform stress distribution in the collar and shaft since the friction between shaft and collar was of the same order of magnitude as the forces involved in the shrinkage. This was overcome by stretching the shaft in tension until its diameter was reduced enough to allow the collar to slip on with slight pressure. After the collar was in place, tension in the shaft was released and shaft was cut off flush with the faces of the collar. The assembled piece was returned to the oil bath at 110°C for one hour and then cooled slowly. This procedure gave a uniform stress distribution in the shaft and collar. However, the value of shear stress determined from the model was found to be about one-half of the value obtained by calcu-



lation. A careful check of all values involved in calculations was made. Another model was made and shear stresses determined experimentally. The results were the same as before. Finally, an assembled model was watched in polarized light while it cooled. The fringe pattern changed as the model cooled. This indicated that this process is not applicable to a case of this kind. The outside of the material cooled before the inside did. This produced a temperature gradient in the material. Also the modulus of elasticity changes as the temperature changes. Since the stress depends on the elasticity of the material, and since this modulus has some varying unknown value during the cooling process which is different for various parts of the model, no significant results could be obtained.

This indicates that three dimensional stress problems for which the magnitudes of the applied forces can vary during the cooling period (due to the changing dimensions of the members) cannot be solved by using the constants determined for the material at  $110^{\circ}\text{C}$ . The load applied to the model must be a constant static load which does not vary during the cooling period in order that the stress fringe pattern obtained at  $110^{\circ}\text{C}$  will exist unchanged at room temperature.

This problem may yet be solvable by photoelastic methods after the physical data relating creep, cooling rate, and thermal expansion coefficient are known. Due to lack of time and uncertainty of results, the shrink fit problem was not carried further.

values over concentrations of  $10^{-10}$  mol/L under  $25^\circ\text{C}$ . The  $\text{K}_{\text{d}}$  values followed a similar pattern where functional groups were less able to form covalent bonds than aromatic hydrocarbons (Table 1). Trends in  $\text{K}_{\text{d}}$  may not fully reflect all the bonding energies due to many other arbitrary factors such as steric hindrance, electron density, and electron distribution. In addition, values will also depend on the nature of the adsorbent and the adsorption conditions. For example,  $\text{K}_{\text{d}}$  values for phenyl groups and  $\text{C}_6\text{H}_5\text{CH}_2$  were found to increase with increasing pH, which may be due to protonation of the phenyl group. However, the  $\text{K}_{\text{d}}$  values for aromatic hydrocarbons did not change significantly with pH. This may be due to the fact that aromatic hydrocarbons are neutral molecules and do not ionize. The  $\text{K}_{\text{d}}$  values for aromatic hydrocarbons were found to decrease with increasing pH, which may be due to the fact that aromatic hydrocarbons are neutral molecules and do not ionize.

The  $\text{K}_{\text{d}}$  values for aromatic hydrocarbons were found to increase with increasing pH, which may be due to the fact that aromatic hydrocarbons are neutral molecules and do not ionize. The  $\text{K}_{\text{d}}$  values for aromatic hydrocarbons were found to decrease with increasing pH, which may be due to the fact that aromatic hydrocarbons are neutral molecules and do not ionize. The  $\text{K}_{\text{d}}$  values for aromatic hydrocarbons were found to decrease with increasing pH, which may be due to the fact that aromatic hydrocarbons are neutral molecules and do not ionize.

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The  $\text{K}_{\text{d}}$  values for aromatic hydrocarbons were found to increase with increasing pH, which may be due to the fact that aromatic hydrocarbons are neutral molecules and do not ionize.

## ROLLER COMPRESSED BETWEEN TWO SLABS

The next problem considered was the case of a roller compressed between two flat slabs. The slabs were made large enough so that the area of the slabs might be considered infinite with respect to the contact area between slab and roller. Figure 14 shows type of model and dimensions. Slices were cut from the YZ and XZ planes. These slices were taken on planes of symmetry so that the principal stress directions lay in the plane of the slice. These slices gave good fringe patterns. Values of  $\sigma_z - \sigma_x$  and  $\sigma_z - \sigma_y$  were determined in the roller and slab. These results are shown in the curves Figure 16, 17, 18 and 19. The value of  $\sigma_x - \sigma_y$  may be found by combining  $\sigma_z - \sigma_x$  and  $\sigma_z - \sigma_y$  shown in the curves. The value of  $\sigma_x - \sigma_y$  could have been measured from slices cut from the XY plane. This was done but the values obtained were unreliable. This was because  $\sigma_x - \sigma_y$  changes from a positive to a negative value near the surface and slices could not be obtained thin enough to determine the distribution accurately. Also, the slice at the surface was not uniform in thickness due to the deformation. In general, it is to be expected that in any model, depending on shape and method of loading, two planes will give a better picture than the third will. In which case it is better to determine the stress in the third plane from the results of the other two rather than to measure it in the third plane.

The large deformation introduces some uncertainty as to the significance of these results. A load of 50 pounds was applied in order to have a suitable number of fringes in thin slices. The fringe pattern from representative sections in the XZ and YZ planes are shown in Figure 8. These results show one interesting point; namely (neglecting ends where stress is concentrated due to sharp edge of the roller), the maximum shear stress

and decreasing within 4-15 min, and low frequency rhythm that will  
also only last 4-8 days while their tone will not change much and same  
duration and at another time additional Arnold's of higher order will be  
performed like the long term approach if you can't perform your daily approach then  
as soon as possible start early off day 13 and after this you will  
not get any additional Arnold's rhythm, and have to go through the whole  
process again, however you can make some changes and be more  
efficient while the rhythm will be discontinued over 20-25 days. If you  
are having any difficulties with this all you need to do is to make your abduc-  
tion and all others  $\frac{1}{2} - \frac{1}{3}$  more  $\frac{1}{2} - \frac{1}{3}$  publications of blood and you  $\frac{1}{2} - \frac{1}{3}$   
will sort this problem and improve your tone from  $\frac{1}{2} - \frac{1}{3}$  to  $\frac{1}{2} - \frac{1}{2}$  by adding more  
and additional more frequency which will not affect much to  
all your other problems of adding a small amount  $\frac{1}{2} - \frac{1}{3}$  because the  
side and movements are done with medium or no tone which you can  
see on condition that you improve and be able to work independently  
from happenings at  $\frac{1}{2} - \frac{1}{3}$  frequency in conjunction with the left shoulder  
like you are asked to know how much to perform again you will  
be better at 11 times Rhythms at  $\frac{1}{2} - \frac{1}{3}$  tone and probably modify a little  
bit you will be getting full tone and good tone and no more tension and movement  
problems. And also at 11 times of both sides  
working on the spectrum tone frequency with number equal but  
now is more of concern and there will be more of a problem when the side  
which you are working with, because when the number of tones addition is  
more or less of tone and finally it has to be the same as the previous one  
because when you get rid of tones above performance you will offend  
yourself because the tone will be gone and the tone will be the same as

occurs at a point below the surface of contact of roller and slab. The location of the points of maximum shear stress are approximately as indicated by V. P. Jensen.<sup>2</sup> The higher the load and the more elastic the material, the farther the point of maximum shear stress is from the contact surface. This indicates that the maximum shear stress is not directly proportional to the total load. The ratio of maximum shear stress to total load decreases as the total load is increased.

The results of the previous test indicated that the total load should be reduced so that deformation would more nearly approximate the deformation permissible in actual construction. A second model was made similar in all respects to the first, except that the corners of the roller were rounded with a 1/8" radius. The load applied was 16 pounds. The results of this test are shown in Figures 20, 21, 22 and 23. A reflection polariscope, Figure 13, was used to get fringe patterns with this model. Figure 15 shows fringe patterns, isoclinics and stress trajectories from representative slices. The slices were cut approximately 0.060" thick. Even with the reflection polariscope, the fringe order was not high enough to get the best results.

This brings out one objection to this method of stress determination. The load must be very small to prevent undue distortion. The slices must be thin to locate points accurately in the model. When these requirements are fulfilled the fringe order is lower than desirable, even when a reflection polariscope is used. This result arises from the fact that, at elevated temperatures the modulus of elasticity is decreased much more than the optical sensitivity is increased; which means that the distortion caused by a stress equivalent to one fringe increases as the temperature goes up.

will make the mailing for January 20, 1912, the most interesting in the year  
and the opportunities are many, varied and numerous for which will be sufficient  
and sufficient time will be given for making a "Record of the Year" of himself  
and with much energy and interest to bring out youthful and pliant  
creations from all sources under his hand and from his skillful art. It is difficult to find  
anywhere more pictures for children's art than those in our Zoobooks.

Alonso (and I) will also be having repeat meetings with the various self-organized units throughout the country over the coming days to discuss the situation. Alonso has been in contact with the military and the members of the Free Syrian Army as well as other local groups and NGOs to discuss the situation. He has also been in contact with the US and UK governments, as well as the European Union, to discuss the situation. Alonso has also been in contact with the UN and the Red Cross to discuss the situation. Alonso has also been in contact with the US and UK governments, as well as the European Union, to discuss the situation. Alonso has also been in contact with the UN and the Red Cross to discuss the situation.

and company needs to know who will be invited and  
from which hot countries, which may be less likely to  
have been to such countries and so provide a better  
basis for our own self-interests and for those who  
are going to be invited to the conference.

## INTERPRETATION OF RESULTS

The general distributions of shear stresses for the 50 pound load and for the 16 pound load are similar. The distortion in both cases was considerably more than would be permitted with steel rollers. Since the general distribution is the same for the above cases, it may be assumed that it approximates the case of steel construction where deformation is still less.

The concentration is not reduced an appreciable amount by rounding the corners of the roller. To reduce the stress concentration at the ends of the roller, the roller would have to be tapered from the center toward each end. The amount of taper would vary directly as the load and inversely as the modulus of elasticity.

There is no theoretical method of computing the stress distribution when the slab extends beyond the roller. The middle section of the roller approximates the case of plane strain as developed by Jensen.<sup>2</sup> Comparison of results computed by Jensen's methods with experimental results shows fair agreement. The results from the model loaded with 16 pounds agree much better with computed results than do results from the model loaded with 50 pounds. This is to be expected, since computed results are based on a rectangular area of contact between roller and slab. In the case of the 50 pound load, the contact area was wider at the ends of the roller than in the middle. The same effect to a much less degree was noted with the 16 pound load. The variation of the shear stress along the Z axis in the roller is as would be expected. It is very low at the surface of contact and increases to a maximum a short distance from the contact surface and then decreases slightly as the center of the roller is approached. At the ends of the roller  $\sigma_s$  is very large due to stress concentration.

Good morning! I hope you're having a nice day so far. I'm writing this email to you because I have some good news to share with you. I am happy to announce that we have received your application for the scholarship and it has been approved. You will receive \$10,000 towards tuition fees for the academic year starting in September. This is a great opportunity for you to pursue your education and achieve your goals. Please let me know if you have any questions or concerns about the scholarship or anything else. I am here to help you every step of the way.

$\sigma_x$  is larger also, as indicated by the increase in the width of the contact area; but  $\sigma_x$  is not increased as much as  $\sigma_z$  and the shear stress is high at the ends of the roller.

Comparison of results for two different loads shows that the shear stresses do not increase in proportion to the load.  $\sigma_z$ ,  $\sigma_x$  and  $\sigma_y$  are all compressive stresses at the surface. As the load increases, the contact area increases and load is distributed over a large area. Since at the surface of contact all stresses are compressions, the shear stress is small. Below the contact surface  $\sigma_x$  decreases rapidly.  $\sigma_z$  does not decrease as rapidly so maximum shear stress occurs below the surface. This explains why rollers and balls will carry large loads on a small area of contact.

Roller bearings which are properly lubricated and carrying a constant load, usually fail due to small cracks and pits on the surface of the roller. Oil is pumped into a small crack causing it to spread; eventually, pitting or spalling render the roller unfit for use. Small cracks may start at a point of maximum shearing stress and work to the surface.

Roller bearings are usually case hardened. The addition of the case would change the stress distribution. Case hardening reduces distortion, increases the load carrying capacity, and reduces friction. With a thick case, closer approach to line contact is obtained and stresses are high. With a thinner case stresses are less, but the maximum shear stress may occur beneath the case where the fatigue limit is low. The proper thickness of the case would depend on load conditions and the physical properties of metal used.

and will be added and no maximum will yet be imposed for under-weight oil  
as we have made up our oil we shall be required over 61 & the same must  
remain with the blow and the right  
parts and other parts would however be left with whatever the weight  
we do have & the same will be nothing as we intend the oil weight  
will remain here and as much as will be necessary afterwards. The  
oil which comes from a new petroleum pool and the material were that  
it would really all consumption was consumed. The problem is, whether after  
we can have a sufficient amount to supply the market for which  
there will be a certain amount and we have to offering at 60  
the larger class is to be used upon whom 62% and the smaller upon

Analysis of individual and community growth variables measured between 1994 and 1995 revealed significant linear trends in all three vegetation types (Table 2). However, slopes were steeper for pasture than for native vegetation, indicating a more rapid loss of cover over time. The mean annual rate of native vegetation decline was 0.003 ha ha<sup>-1</sup> year<sup>-1</sup>, while the mean annual rate of pasture decline was 0.012 ha ha<sup>-1</sup> year<sup>-1</sup>. The mean annual rate of decline for the mixed vegetation type was 0.006 ha ha<sup>-1</sup> year<sup>-1</sup>.

## CONCLUSIONS

### 1. Technique or methods of procedure.

- a. Models used for study should be as large as possible. The maximum thickness of Bakelite available was 1". Models two or three times larger would give better results.
- b. Slices cut from models should be as thin as possible and yet retain a sufficient number of fringes.
- c. The models must be so loaded as to keep distortion within reasonable limits.
- d. Fulfillment of (b) and (c) makes the use of a reflection polariscope desirable.

### 2. Press fit problem.

- a. The magnitude of the applied force varied during the cooling period.
- b. Stress evaluation based on the constants of Bakelite at 110°C was not correct.

### 3. Roller compressed between two slabs.

- a. No analytical solution is available for this case. Stress conditions in the middle section of the roller approximate the conditions of plane strain. The degree of agreement between computed results and experimental results indicates that the method is applicable to a case of this kind.
- b.  $\sigma_z - \sigma_x$  may be computed with reasonable accuracy by Jensen's<sup>2</sup> curves.  $\sigma_z - \sigma_y$  cannot be computed by means of Jensen's method.

with which we must be all aware who are here gathered together.

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*Journal of Applied Mathematics and Computation* 2013: 1–13.  
http://dx.doi.org/10.1007/s40314-013-0001-1

如欲知其更詳細的資料，請參閱《中華書局影印》。

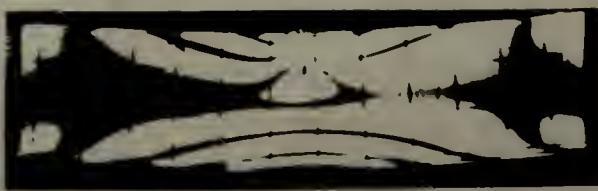


FIGURE 1



FIGURE 4



FIGURE 2



FIGURE 3



FIGURE 5



FIGURE 6. OIL BATH USED FOR HEATING MODELS



FIGURE 7 LOADING DEVICE



FIGURE 8. FRINGE PHOTOGRAPHS OF SLICES CUT FROM MODEL





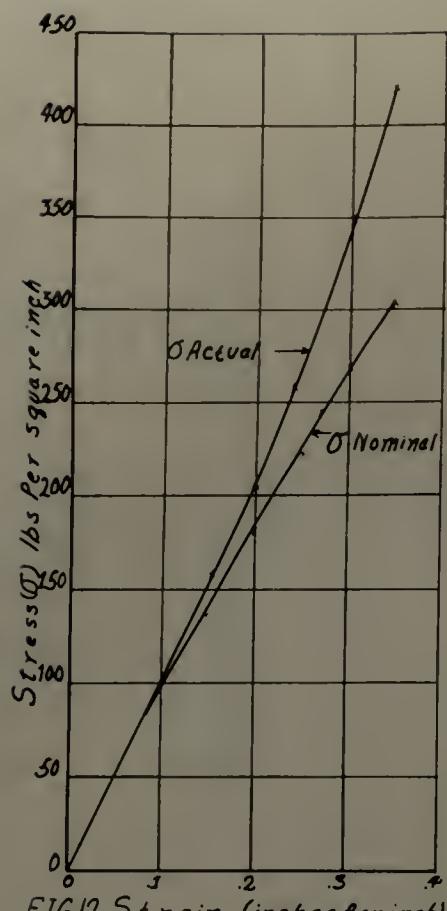


FIG 12. Strain (inches per inch)

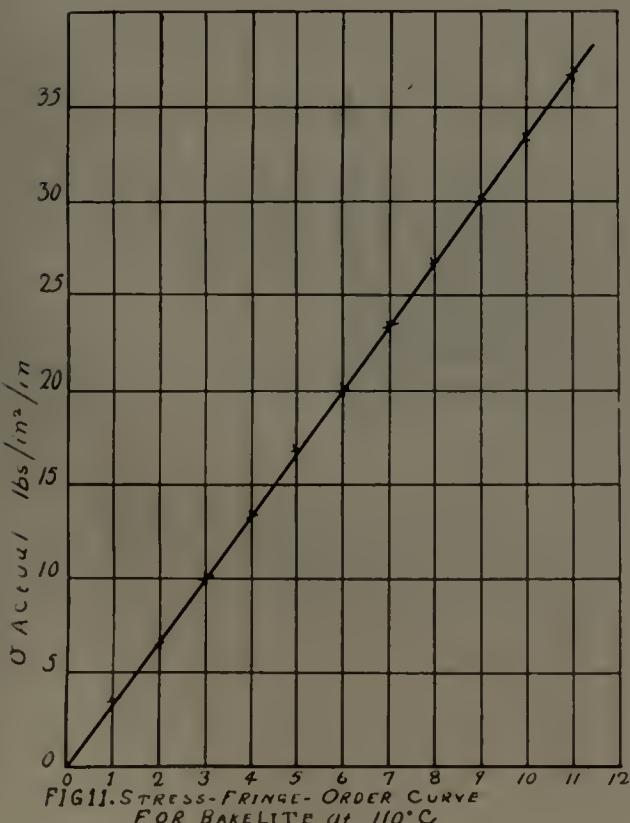


FIG 11. STRESS-FRINGE-ORDER CURVE  
FOR BAKELITE AT 110°C

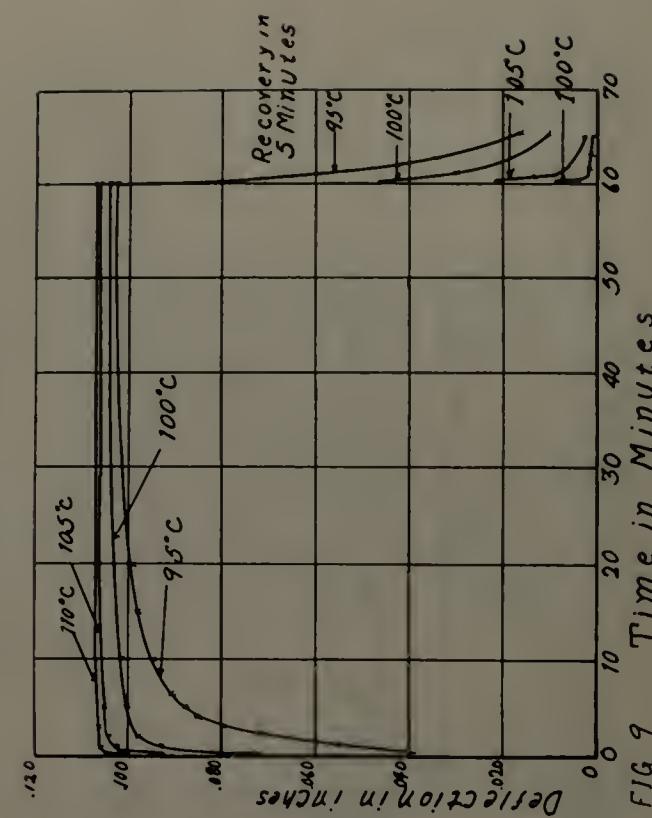


FIG 9. TIME IN MINUTES  
DEFLECTION IN INCHES

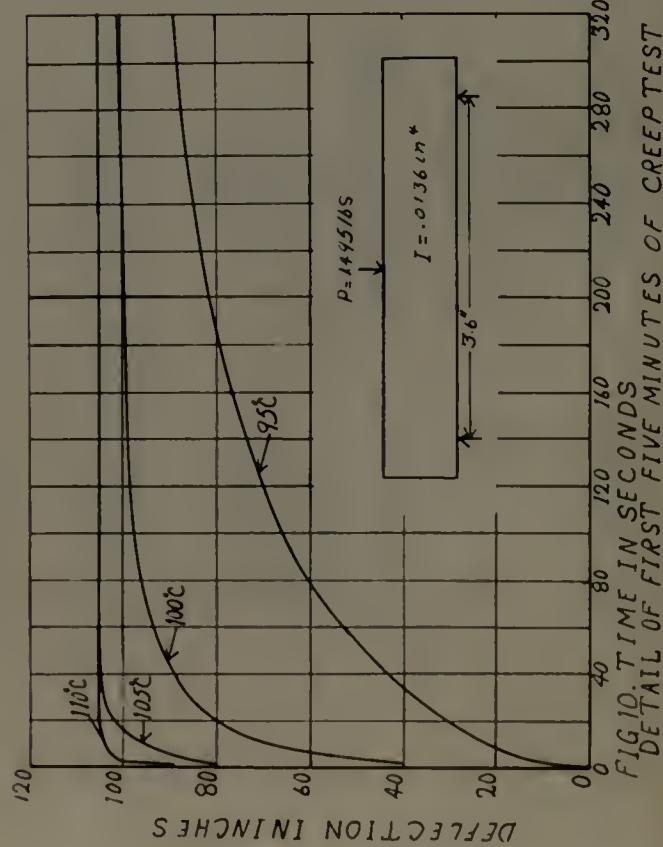
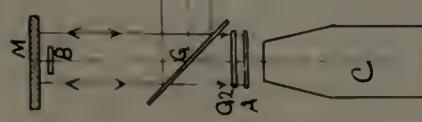


FIG 10. TIME IN SECONDS  
DEFLECTION IN INCHES

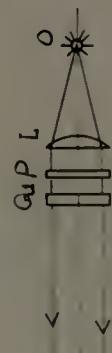




REFLECTION POLARISCOPE

O = LIGHT SOURCE  
L = LENS  
P = POLARIZER  
Q<sub>1</sub> = QUARTER WAVE PLATE  
B = SPECIMEN  
G = GLASS PLATE  
M = MIRROR  
A = ANALYZER  
C = CAMERA

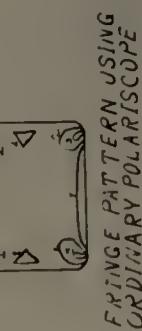
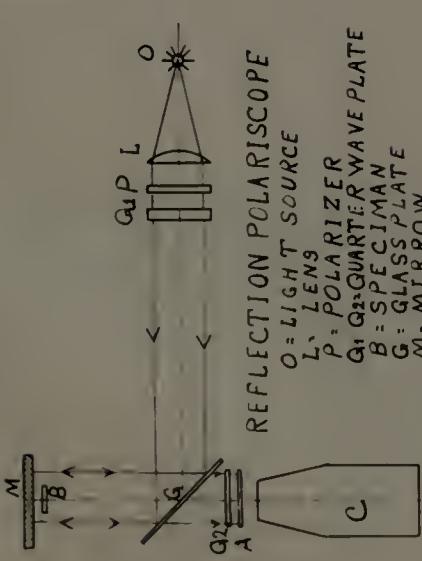
FIG 13



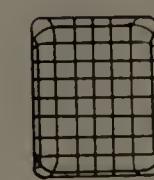
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O = LIGHT SOURCE  
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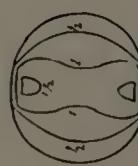
FIG 13



FRINGE PATTERN USING ORDINARY POLARISCOPE



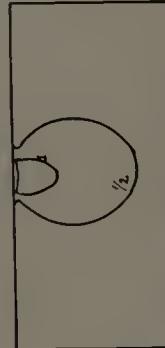
STRESS TRAJECTORIES CENTER SECTION OF ROLLER YZ PLANE



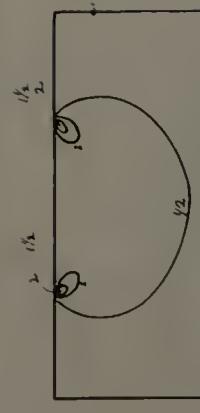
STRESS TRAJECTORIES CENTER SECTION OF SLAB XZ PLANE



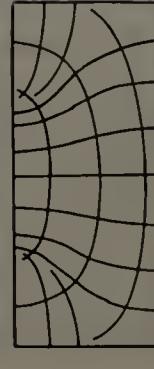
STRESS TRAJECTORIES CENTER SECTION OF SLAB YZ PLANE



FRINGE PATTERN USING REFLECTION POLARISCOPE



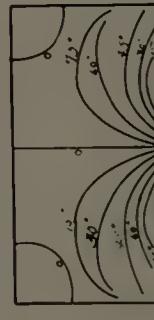
FRINGE PATTERN USING REFLECTION POLARISCOPE



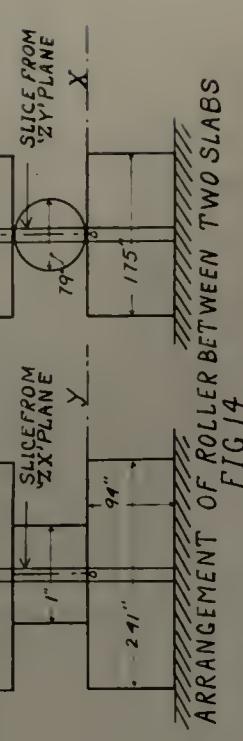
STRESS TRAJECTORIES CENTER SECTION OF ROLLER YZ PLANE



STRESS TRAJECTORIES CENTER SECTION OF SLAB XZ PLANE

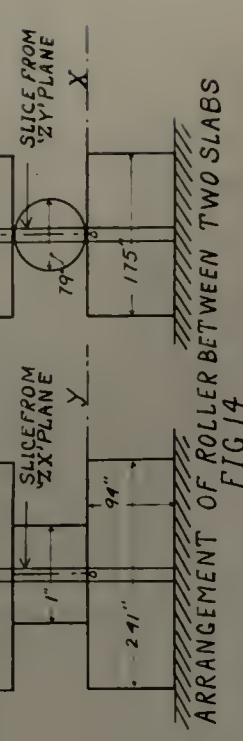


STRESS TRAJECTORIES CENTER SECTION OF SLAB YZ PLANE



ARRANGEMENT OF ROLLER BETWEEN TWO SLABS

FIG 14



ARRANGEMENT OF ROLLER BETWEEN TWO SLABS

FIG 14

FIG 15 FRINGE PATTERNS, STRESS TRAJECTORIES AND ISOCLINICS FROM REPRESENTATIVE SLICES OF ROLLER AND SLAB ( $P' = 16 \text{ lbs}$ )



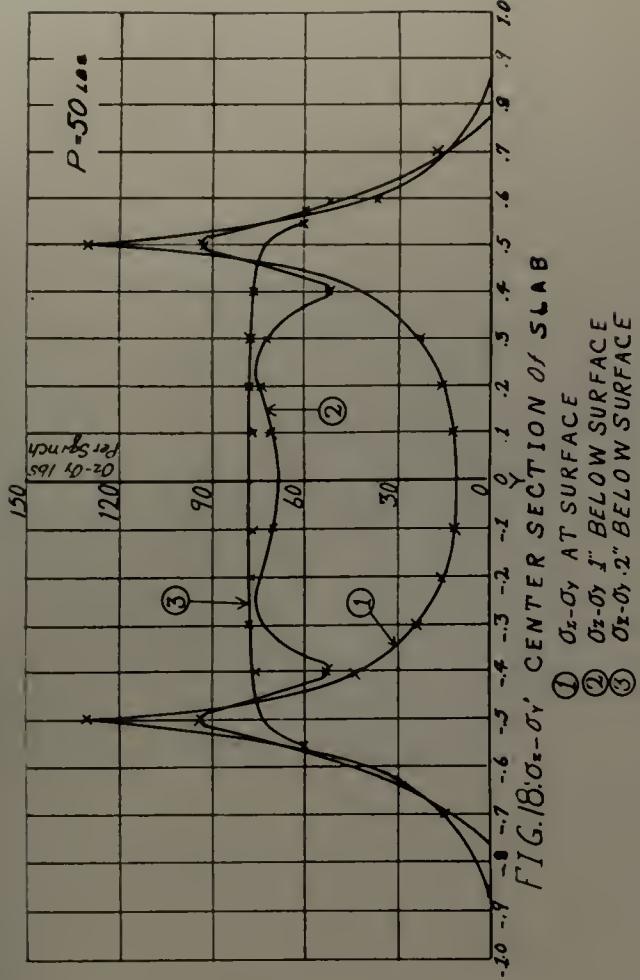
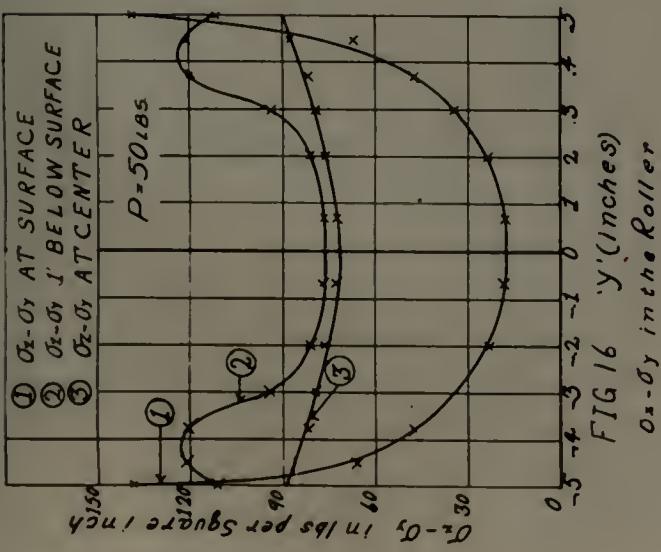


FIG 16  
 CENTER SECTION OF SLAB  
 ①  $\sigma_x - \sigma_y$  AT SURFACE  
 ②  $\sigma_z - \sigma_y$  1' BELOW SURFACE  
 ③  $\sigma_z - \sigma_y$  2' BELOW SURFACE

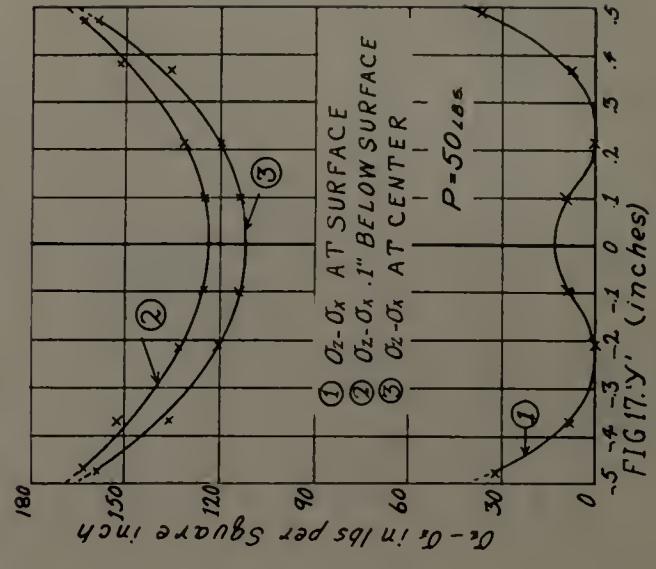
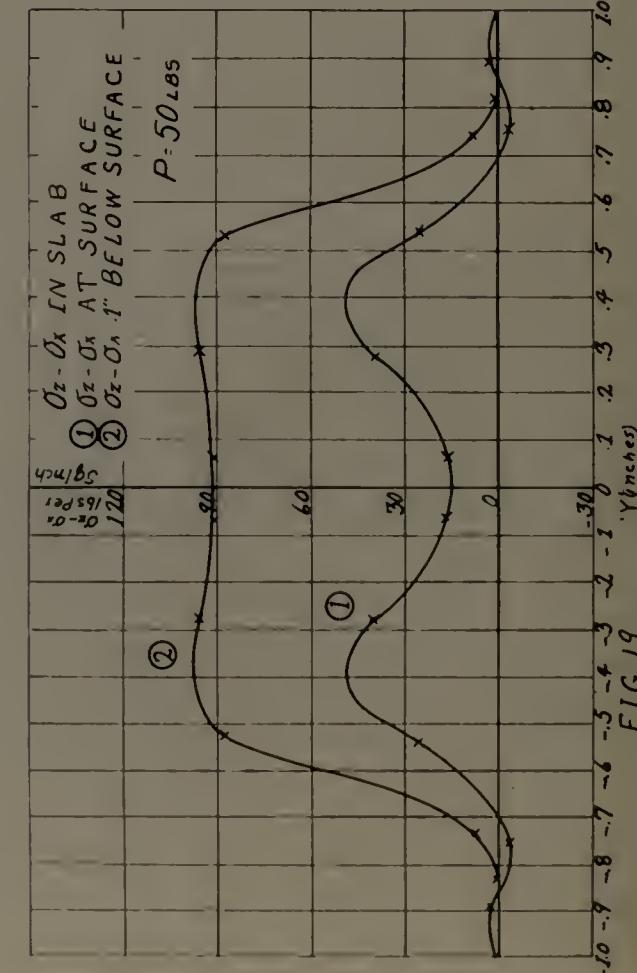
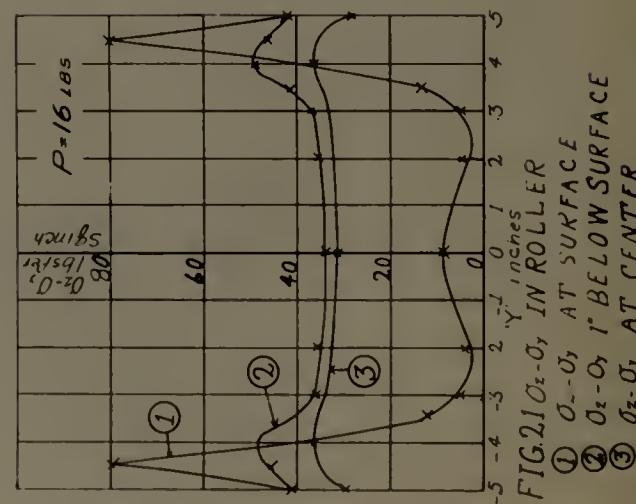
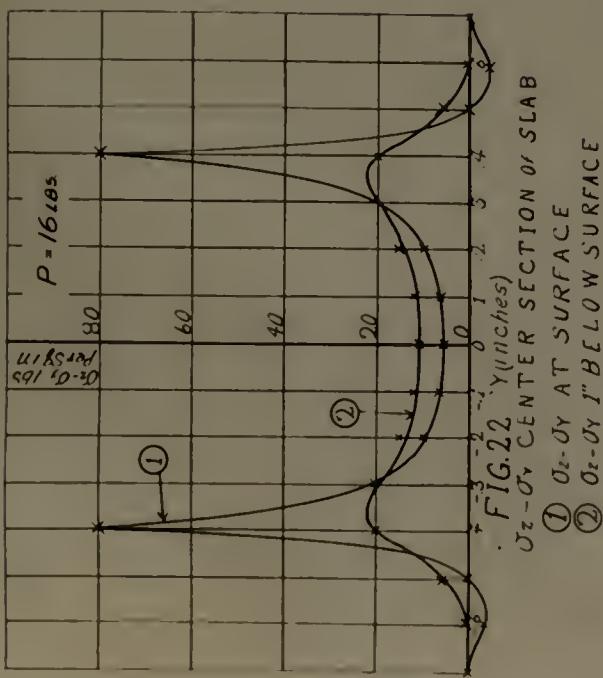
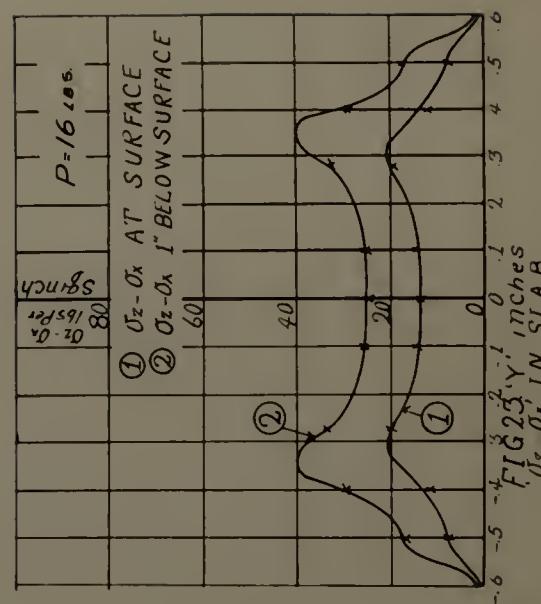
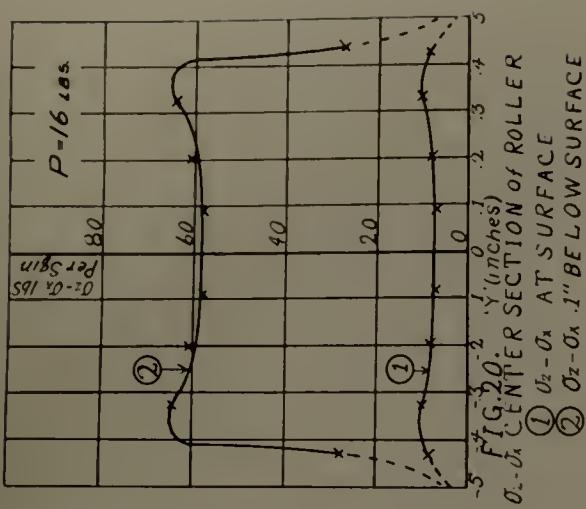


FIG 17  
 'O<sub>x</sub> - O<sub>y</sub>' IN ROLLER















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